

PHASE III  
PROGRESS REPORT

FOR

AUGUST 1966

RESEARCH AND DEVELOPMENT FOR  
FABRICATING A TITANIUM ALLOY

GORE SEGMENT

NAS 8-20534 (14)

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FACILITY FORM 802

**N67-83798**  
(ACCESSION NUMBER)

14  
(PAGES)

CR-84128  
(NASA CR OR TMX OR AD NUMBER)

(THRU)

None  
(CODE)

(CATEGORY)

Prepared for

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## SUMMARY

This report covers the period from August 1 to September 1, 1966 of NASA Contract NAS 8-20534. During this period, the first full size titanium gore segment was successfully hot vacuum formed. Visual inspection of the part in the die indicates that the part is approximately 0.125 inches maximum off the die in the area around the porthole opening. All the edges of the part are net to the die except in the corners where 0.032 inch shims were placed to prevent damage to the die. There were small waves in the corner pockets of the part. The largest wave was approximately 4 inches wide, 10 inches long, and  $\frac{1}{4}$  inch deep. The discrepancies in the formed part were insignificant in relation to over-all forming success. To form the first part with a high degree of success, a framework of  $\frac{1}{2}$  inch thick, 2 inch wide titanium was welded around the periphery of the part prior to forming to prevent buckling. A heatup time of 4-3/4 hours was used to bring the part temperature to 1450° F. The soak time at temperature was 12 $\frac{1}{4}$  hours. At the beginning of the soak period, the vacuum was started at 1/8 inches of Hg. The part was bottomed to the die near the end of the soak period with a maximum of 4-3/4 inches of Hg. At the end of the soak period, the vacuum was increased to 27 $\frac{1}{2}$  inches of Hg. At this point, the cool down cycle was started and the vacuum was reduced. At the end of the cool down cycle of 5 $\frac{1}{2}$  hours, the part temperature was about 1150° F and vacuum was zero. The total forming process time was 22 $\frac{1}{2}$  hours. Although there are a number of processes yet to be accomplished on the formed part, the hot vacuum forming process can be deemed highly successful.

The status of the other two titanium gore segments is included in the report.

A revised budget and schedule is currently being negotiated between Boeing and NASA.

### FORMING OF FIRST FULL-SIZE TITANIUM GORE SEGMENTS

As indicated in previous reports the major problem of forming the gore segment was buckling. Our previous tests with aluminum and steel indicated that buckling could be minimized by certain methods. These methods were as follows:

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1. Weld a framework to the periphery of the part,
2. Use the maximum temperature allowed.
3. Use a low vacuum to accomplish forming,
4. Form over a long period of time.

All these methods were used in forming of the first titanium gore segment.

After machining, a framework was welded to the periphery of the part. Five pieces of 2 inch wide strips were plasma arc cut from 6 inch wide  $\frac{1}{2}$  inch thick 8-1-1 titanium plate. These five pieces were enough to completely encompass the periphery of the part. Plasma arc cutting was used because it was fast, economical and close tolerance was not necessary. The framework was clamped to the edge of the part, and the framework was fillet welded to the  $\frac{1}{2}$  inch thick excess of the part. Both the inside and outside edges were welded.

The gore segment was cleaned, phosphate-fluoride coated, and sprayed with formcoat (Everlube) T-50 lubricant.

In the meantime, shims to fill the pocketed area were fabricated. The shims were sheared from 321 stainless steel sheet 0.063 x 36 x 120 inches. The shims were sheared  $\frac{1}{4}$  to  $\frac{1}{2}$  inches smaller than the pocketed area as closer tolerance was not deemed necessary. Some of the shims were not coated with Everlube T-50. A few of the pockets were left without shims. A total of 6 shims were used in those pockets in which shims were placed. The reason some shims were not coated with Everlube T-50 and some pocketed areas were left without shims was to save money and time and at the same time determine the value of the coating and the shims. When the steel diaphragm was used, the shims were mandatory to transmit the vacuum pressure to the pocketed area. With the nylon diaphragm, theoretically, the shims are not necessary; however, shims were used to exercise every precaution in forming the first part.

The part was located in the die as shown in Figure 1. The 24 thermocouples were attached to the part in the areas shown in Figure 2. To prevent the insulation from falling between the part and the die, 0.020 inch thick stainless steel strips were placed from the part to the edge of the die. The strips were attached to the excess on the edge of the part by rivets. The part was now ready for insulation.

Two layers of 1/2 inch thick Kaowool were used to cover the part to the edges of the die. A 0.030 inch thick blanket of fiberglass cloth was laid over the Kaowool insulation. Vermiculite was poured on the fiberglass blanket to a depth of 5 inches. The 0.005 inch thick nylon diaphragm was the final covering of the insulation. The diaphragm was sealed to the outer flange of the die with black tape,

At this point the part was ready to begin the forming operation. The electrical power was switched ON and the controllers for the die were set at 1500° F. To prevent ballooning of the diaphragm during the heat-up, the vacuum pump was operated to maintain equilibrium. The part reached 1453° F in 4-3/4 hours as indicated by the average readings of the 24 thermocouples attached to the part. The highest thermocouple reading on the part was 1480° F and the lowest was 1430° F. Of the 24 thermocouples, one did not operate properly. There were 14 die thermocouples used to record the die temperature. At the end of the heat-up cycle the average readings of the 14 die thermocouples was 1572° F. One thermocouple did not record properly. The highest temperature recording was 1590° F and lowest 1550° F. Figure 3 shows the temperature curves during the forming operation. At the end of the heat-up period, the part had sagged 7 inches into the die from its own weight as shown in Figure 4.

The soak period of 12 1/4 hours was begun and a vacuum of 1/8 inches of Hg was established. The average part temperature during the soak period was 1492° F. The highest recording was 1525° F and the lowest 1450° F. The average temperature of the die during the soak period was 1533° F. The highest temperature of the die was recorded at 1555° F and the lowest was 1525° F. See Figure 3 for temperature curves during the soak period. During the first 9 hours of the soak period, the vacuum was increased from 2 to 4-3/4 inches of Hg and deflection increased from 13 to 14-3/4 inches which was bottom. The vacuum was increased to 27 1/2 inches of Hg the last 1-1/4 hours of the soak period.

The cool down cycle was started and the vacuum was seduced slowly to zero over a period of  $5\frac{1}{2}$  hours. The average temperature of the part after  $5\frac{1}{2}$  hours of cooling was  $1165^{\circ}$  F. The highest temperature was  $1205^{\circ}$  F. The average temperature of the die was  $1144^{\circ}$  F. The highest die temperature after  $5\frac{1}{2}$  hours of cooling was  $1225^{\circ}$  F and the lowest  $1005^{\circ}$  F. The die temperature was checked  $16\frac{1}{2}$  hours later and was between  $800$  and  $900^{\circ}$  F. The die temperature  $52\frac{1}{2}$  hours after the  $5\frac{1}{2}$  hour cool down cycle was  $450-550^{\circ}$  F. When the die temperature was between  $450-550^{\circ}$  F, the diaphragm and insulation was removed. The part was net to the die on all four sides except at the corners where 0.032 inch shims were placed to protect the die from the sharp corners of the part. The part was a maximum of 0.125 inches off the die at the porthole opening. At the center of the part and the surrounding area the part was less than 0.10 inches from the die. In the corner pocket areas there were waves. The largest wave was about 4 inches wide, 10 inches long, and 0.25 inches deep. Figure 5 shows the full size titanium gore segment in the vacu-die after the forming operation. Although the gore segment had small waves in the corner pockets and was off the die 0.125 inches about the porthole, the forming operation was deemed highly successful.

After the part had been pocket machined, the crack around the diffusion bonded area was removed by machining. As previously reported, this crack occurred after the diffusion bonding operation. Figure 6 shows the crack. The crack was approximately 20 inches long and to within 0.060 inches of being through the part. The cracked area was then hand welded with filler wire. The welding was done very slowly to minimize weld distortion and further cracking. The welding was accomplished successfully as seen by visual inspection and shown in Figure 7. At a later date before shipment to NASA the welding will be penetrate inspected.

#### RESULTS OF THE DIFFUSION BONDING INSPECTION

Previous to the forming of the first titanium gore segment, the diffusion bonded ring around the porthole was ultrasonic inspected. The bond line was inspected and recorded using the "C" scan method. The "C" scan method locates the target in the plan view and the target size is shown by intensity. Instrument sensitivity was adjusted to record defects approximately 0.015 inches in diameter and above. No significant discrepancies were detected.

## PROGRESS IN FABRICATING THE THREE PARTS PER SK-P1-1165

Part #1 originally was planned to be the first part to be formed but circumstances changed so that Part #2 was ready for forming first. Part #1 is currently being machined and is scheduled for hot vacu-forming approximately September 20, 1966. Part #2 has been formed. The excess and framework is currently being trimmed from the part. After the part is trimmed, it will be cleaned. Further work will be suspending pending current contract negotiation for budget and scheduling. Part #3 has been diffusion bonded, stress relieved, and hot flattened. At the present time all work has been suspended on this part pending the results of budget and schedule negotiation between Boeing and NASA.

## TECHNICAL PROBLEMS

The majority of the forming problems disappeared with the successful forming of the first gore segment. However, the waves in the corner pockets of the part present a problem to be solved. How the waves are to be removed from the formed gore segment and how the waves can be prevented from occurring in future parts has not been decided.

As previously reported one of the titanium plates, part #3, was received from the mill with two waves on one end. These waves were about a foot apart and were across the eight foot width of the part. Before the first hot flattening the waves were 0.30 inches in height. Hot flattening at 1250° F with 25 tons of weight on the part removed some of the waviness but the height of the waves was still 0.22 inches. A subsequent hot flattening operation at 1450° F with 40 tons of weight on the part reduced the wave height to 0.12 inches. These waves present a machining problem. The best answer to solve the problem at this time is make a 0.12 inch cut on the back side of the plate prior to pocket machining. The plate varies in thickness from 0.50 to 0.70 inches. Taking the 0.12 inch cut on the back side will give a variance in the rib height and about the porthole opening, but will make possible the machining of the pockets to tolerance.

Currently all work has been suspended on this part pending results of budget and schedule negotiations between Boeing and NASA.

As stated above, extra care was exercised in forming the part in an effort to form successfully. Before the next part is formed, a number of changes in the forming operation could be made to attempt to simplify the operation. These changes are in regard to reducing the soak time, increasing vacuum pressure at a faster rate, eliminating the use of pocket shims, and eliminating the framework. A future discussion with NASA personnel about these possible changes and their desires will determine our direction of effort. There is an unknown risk involved in making any of these changes. Elimination of the framework will present the most risk.

In the last report it was recommended that an inert atmosphere not be used. In a subsequent discussion with NASA personnel, it was agreed that the inert atmosphere would not be used.

#### SCHEDULE AND BUDGET PROBLEMS

An extension of the final completion date and an increase of the budget for the contract is currently being negotiated with NASA.

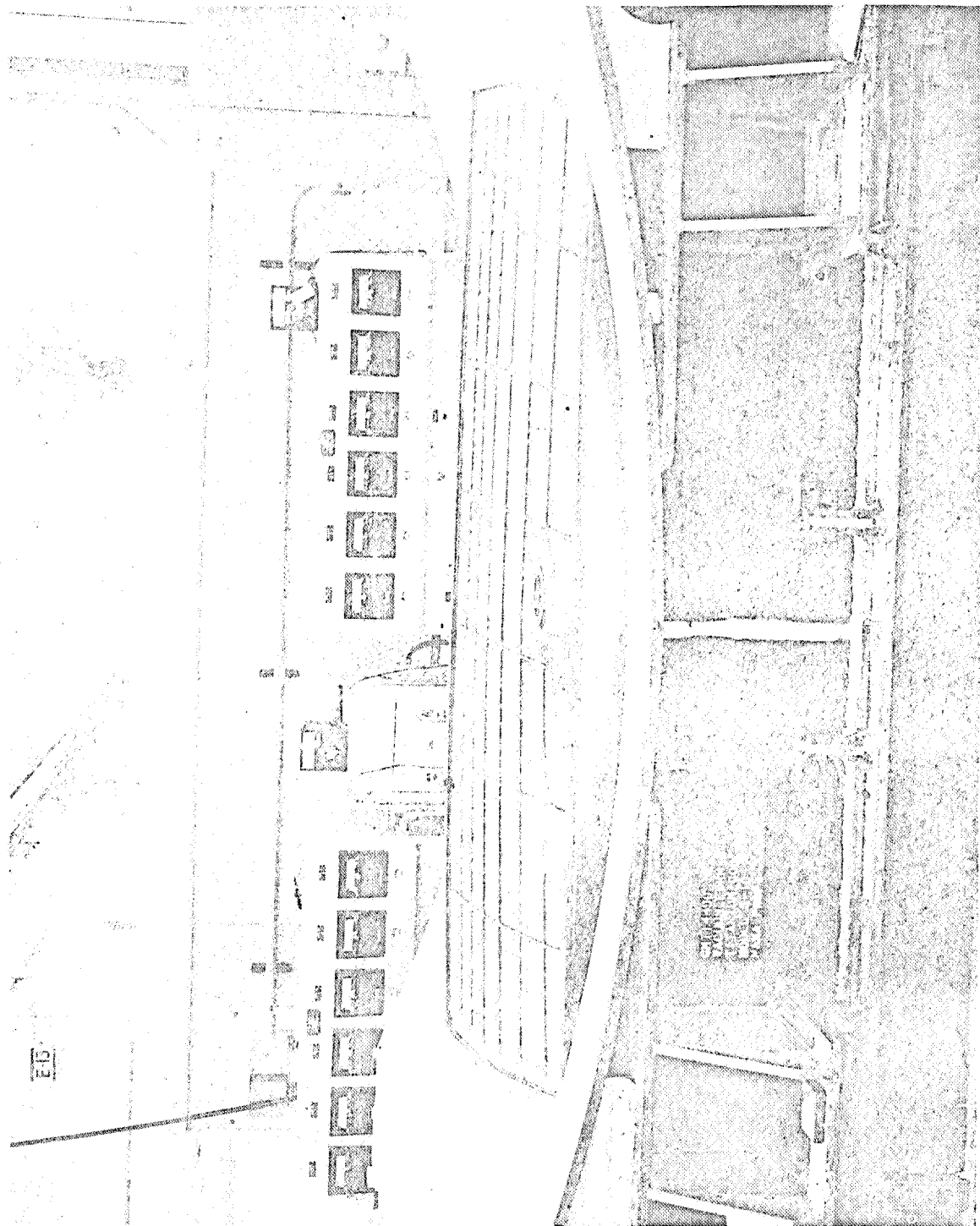


FIGURE 1

THE TITANIUM GORE SEGMENT LOCATED IN THE VACU-FORM DIE  
PRIOR TO COVERING WITH INSULATION AND THE NYLON DIAPHRAGM

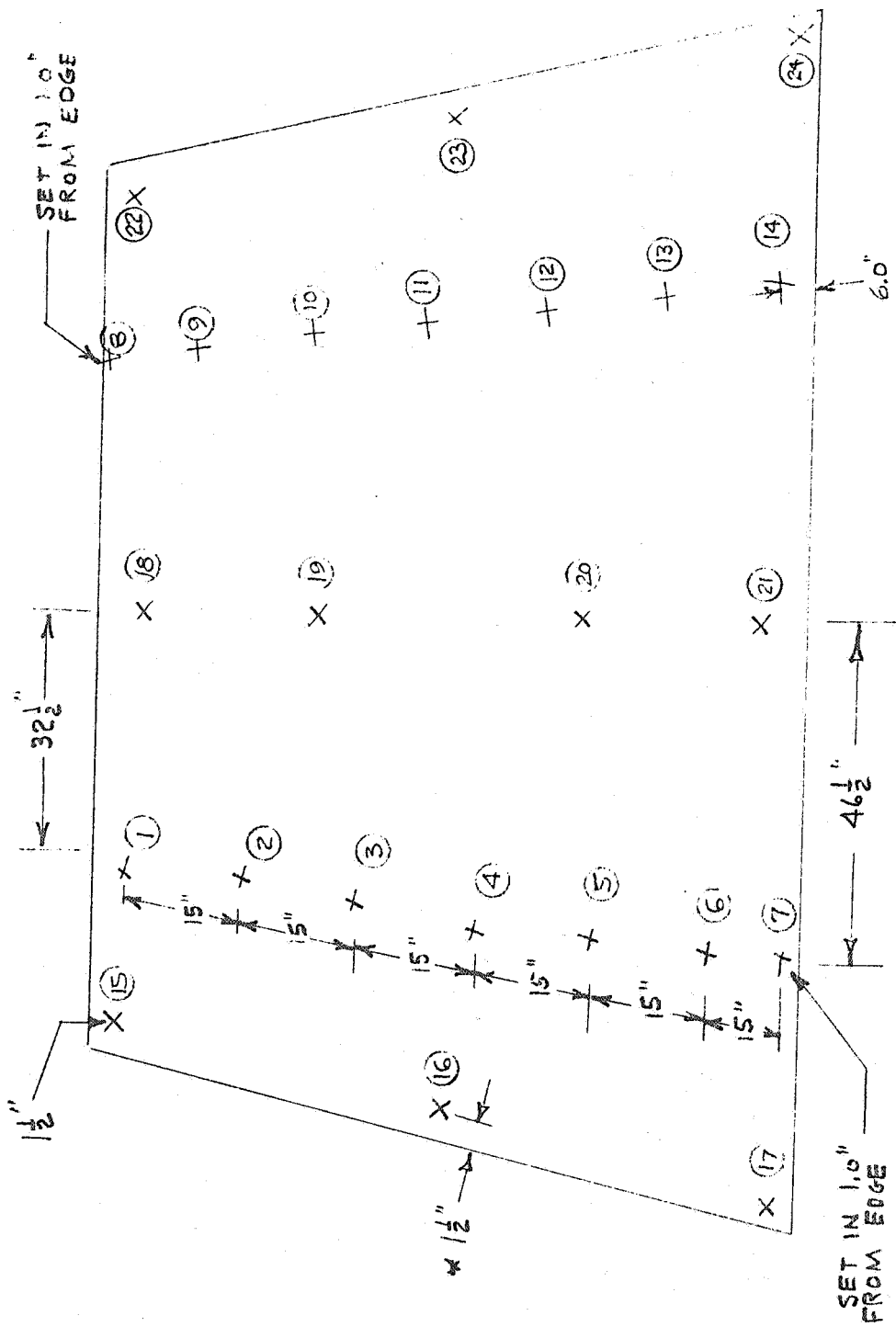
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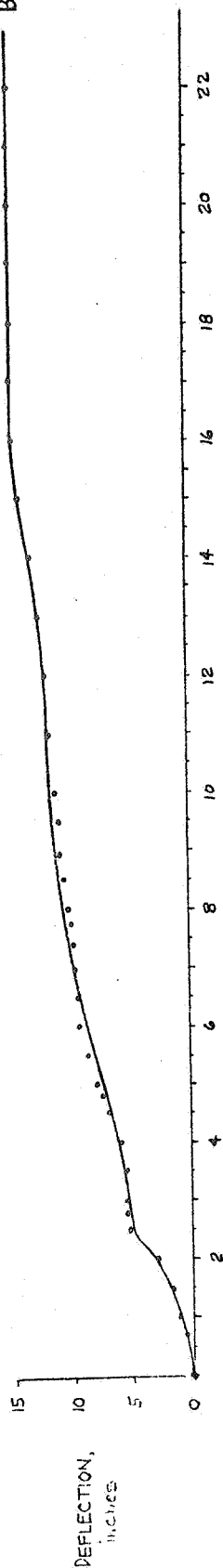


# THERMOCOUPLE LOCATIONS - TITANIUM GORE

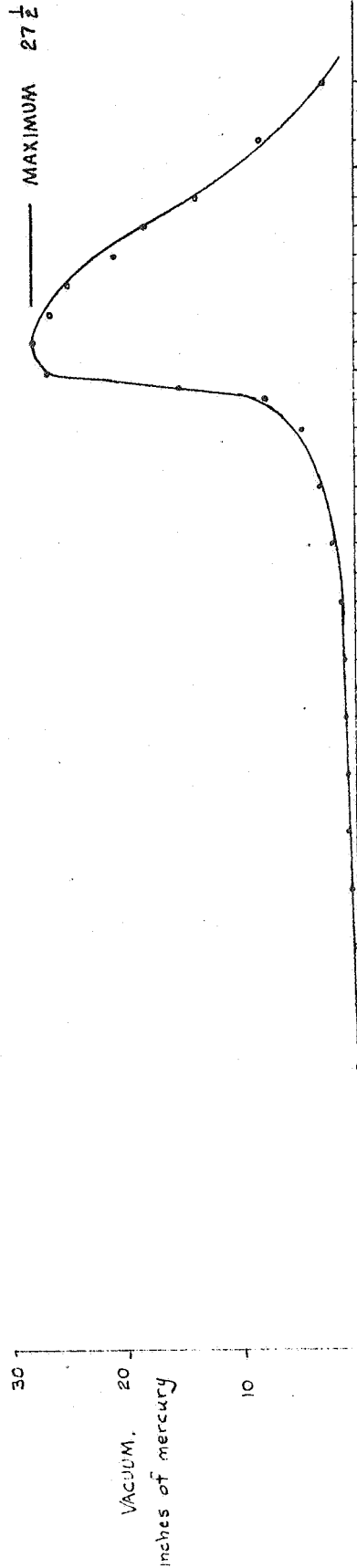
1 1/2" TYPICAL (15) (16) (17) (18) (21) (22) (23) (24)

IRE 2

BOTTOM  
14.3"  
14.4"



MAXIMUM 27 1/2" of Hg



SOAK PERIOD 12 1/4 HOURS AT 1500°F

HEAT - UP  
4 3/4 HOURS

COOL DOWN CYCLE 5 1/2 HOURS

DIE THERMOCOUPLES  
PART THERMOCOUPLES

TIME, hours

FIGURE 3

INITIALS	DATE	REV BY INITIALS	DATE	TITLE	MODEL
ALC	8-24-66			NASA GORE DIE TEST	
CHECK	8-26-66			SCULPTURED 8-1-1 TITANIUM PART	
APPD				TIME VS. TEMP, VACUUM, & DEFLECTION	
APPD				AUGUST 12, 1966 ±0.4 AM	

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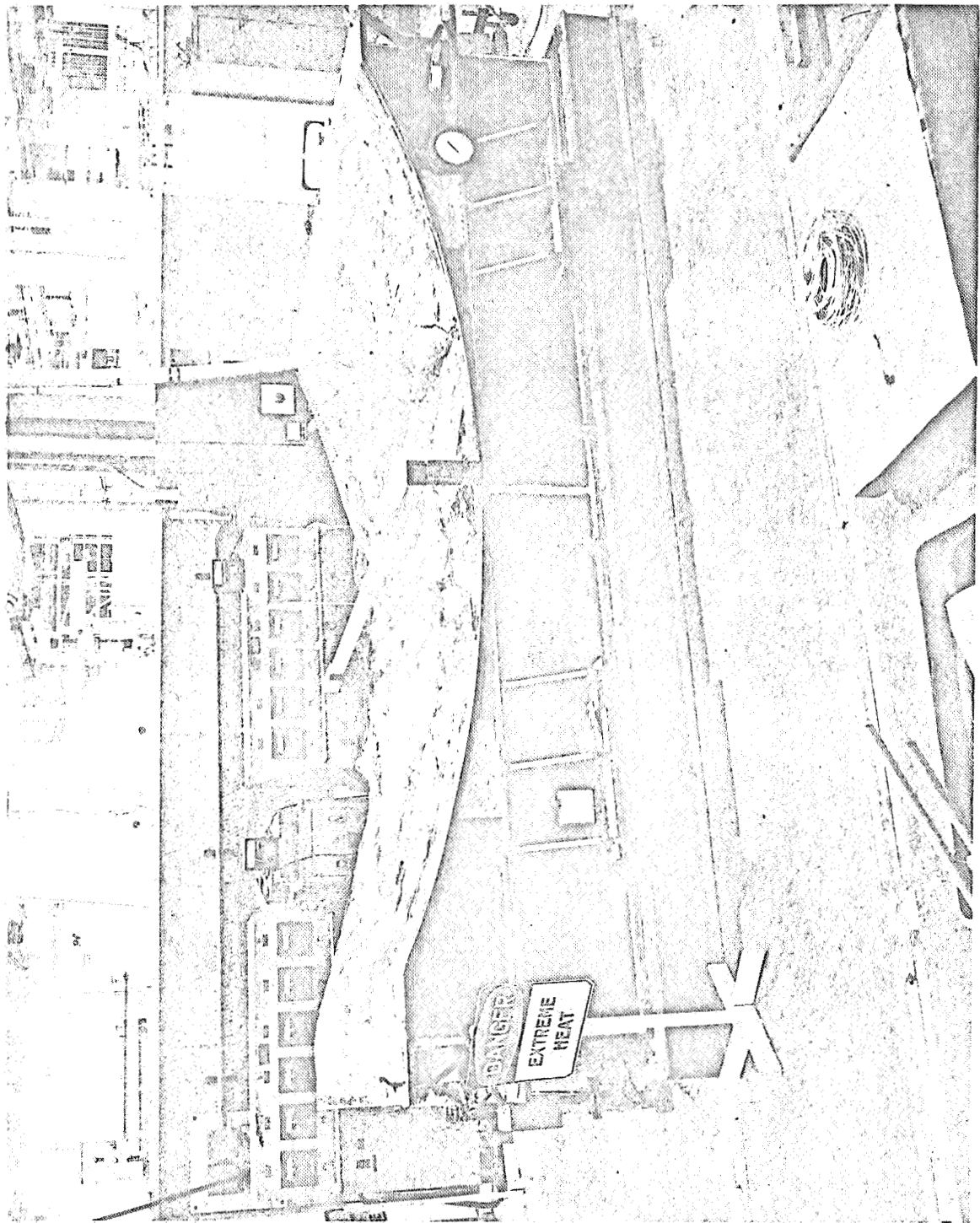


FIGURE 4  
VIEW OF THE VACU-DIE DURING THE FORMING OPERATION.  
THE PART IS IN THE DIE AND IS COVERED WITH INSULATION  
AND A NYLON DIAPHRAGM.

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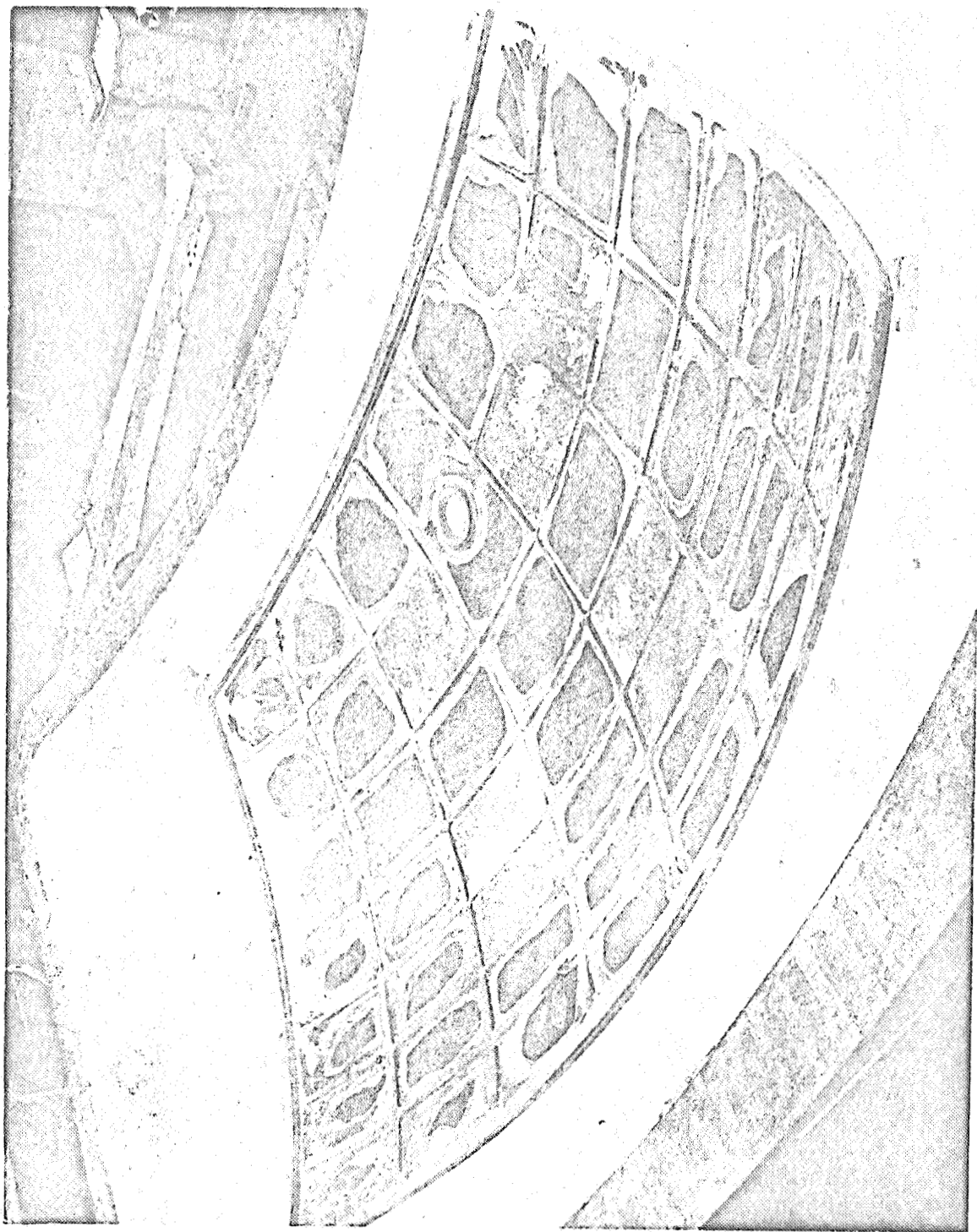


FIGURE 5  
VIEW OF FULL-SIZE 8-1-1 TITANIUM GORE SEGMENT  
AFTER HOT VACUUM FORMING

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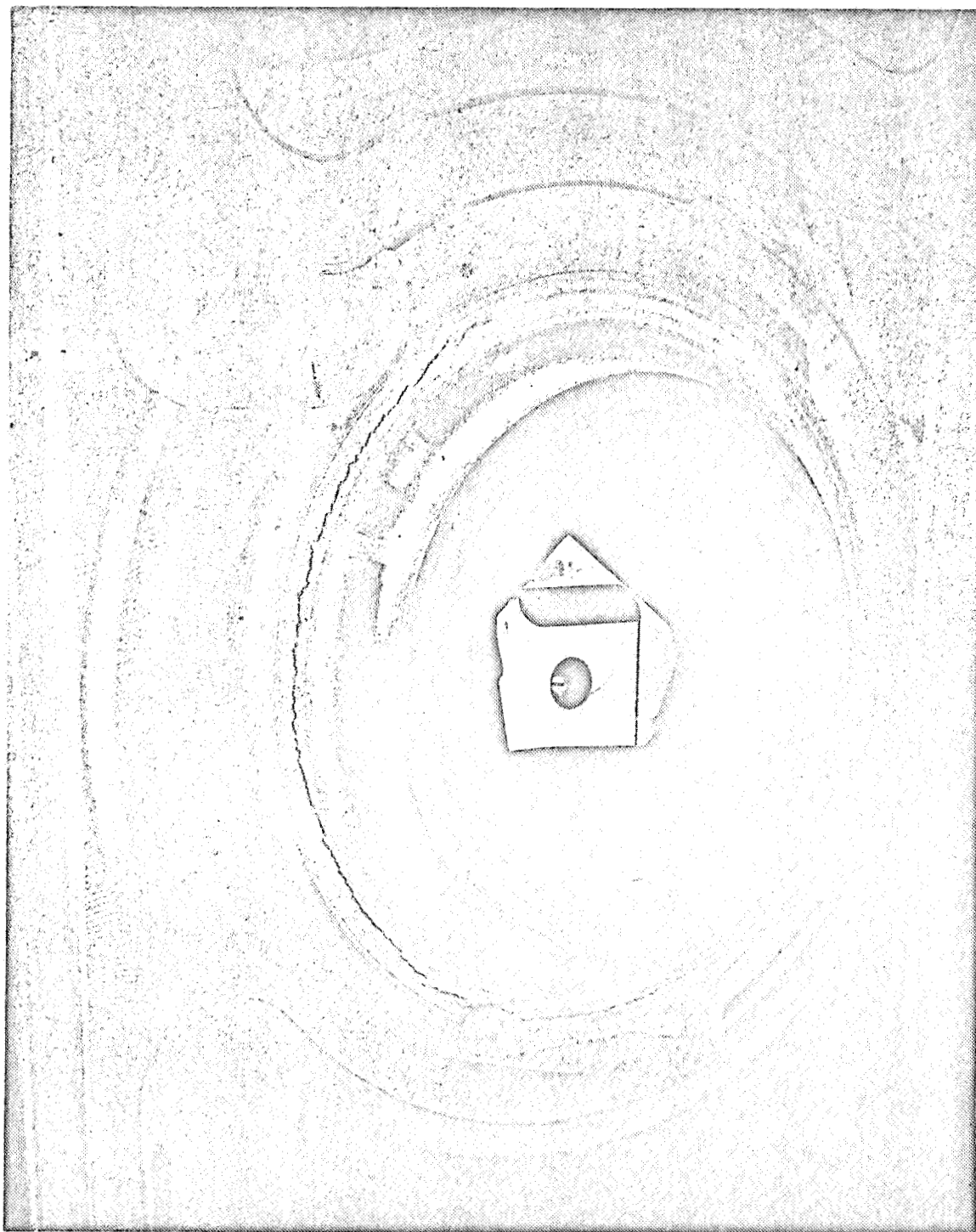


FIGURE 6  
CLOSE UP VIEW OF THE CRACK AROUND THE PORTHOLE.  
THE CRACK DEVELOPED AFTER THE DIFFUSION BONDING OPERATION.  
CRACKS DID NOT DEVELOPE ON SUBSEQUENT PARTS.

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FIGURE 7:  
VIEW OF DIFFUSION BONDED AREA AFTER CRACKED SECTION  
HAS BEEN HAND WELDED AND THE GORE SECTION FORMED.

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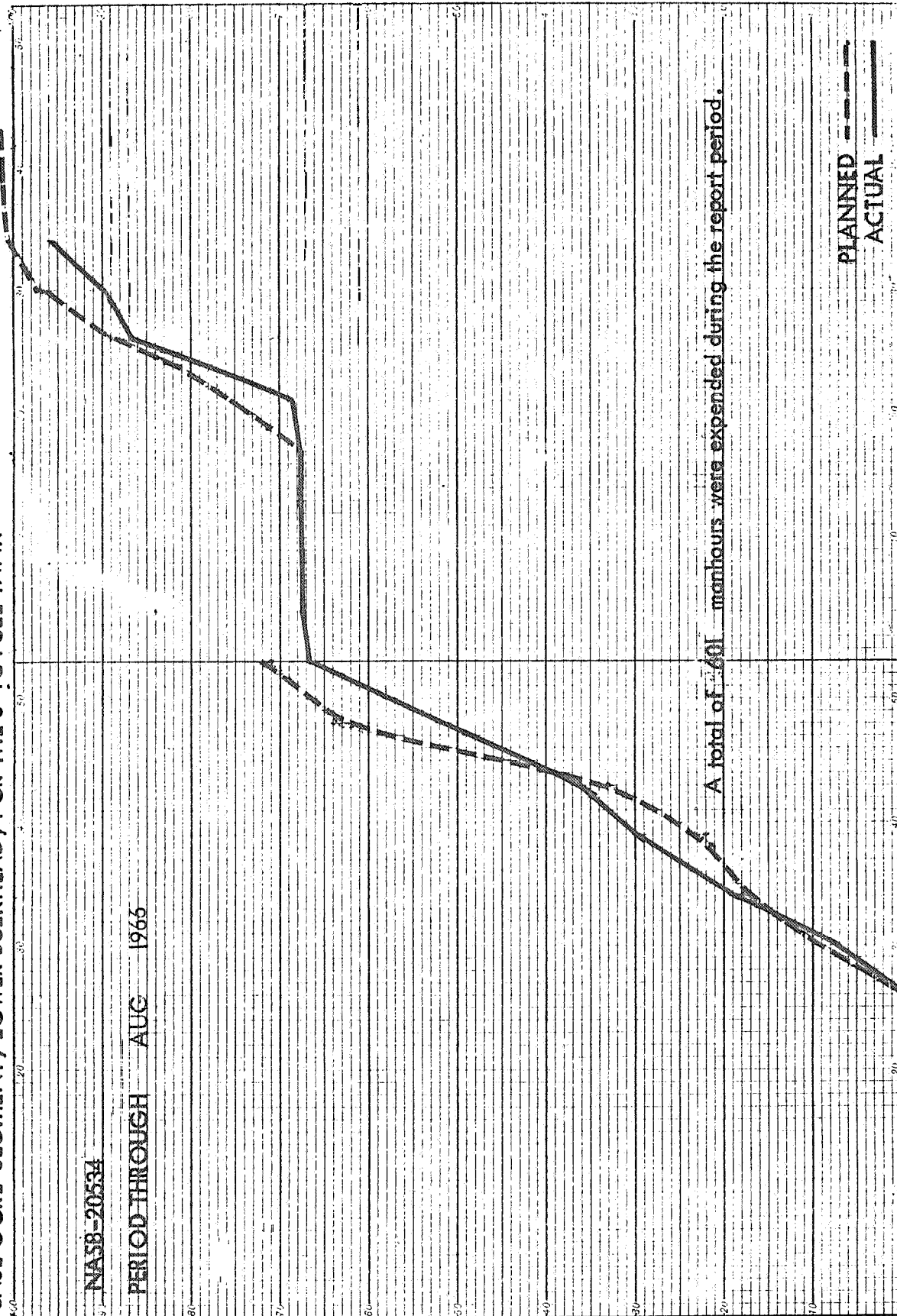
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# RESEARCH & DEVELOPMENT FOR FABRICATING A SIMULATED TITANIUM ALLOY BASE GORE SEGMENT, LOWER BULKHEAD, FOR THE S-1C FUEL TANK

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PERIOD THROUGH AUG 1966



PLANNED MANHOUR EXPENDITURES

1965

1966